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PREVIOUS YEAR QUESTION (2024 PATTERN)

1. LASER

1.1 Spontaneous & Stimulated Emission

- Q. Define Stimulated emission. (Nov 2024)
- Q. What is stimulated emission? Explain its significance in the production of lasers. (April 2025)

1.2 Population Inversion

- Q. Define Population inversion. (Nov 2024)

1.6 Characteristics of Lasers

- Q. State characteristics of a laser. Explain any one of them in brief. (April 2025)
- Q. What is a LASER? State important characteristics of a laser. (Nov 2024)

1.7 CO₂ Laser — Construction & Working

- Q. With a neat labelled diagram, explain the construction and working of a CO₂ laser. (Nov 2024)
- Q. With the help of an energy level diagram, explain the construction and working of CO₂ laser. (April 2025)

2. OPTICAL FIBERS

2.2 Acceptance Angle

- Q. Calculate the numerical aperture and acceptance angle of an optical fiber having $n_1 = 1.48$, $n_2 = 1.45$ (April 2025)

2.4 Numerical Aperture (NA)

- Q. An optical fiber has core refractive index 1.55 and cladding index 1.46. Calculate Numerical Aperture (NA). (Nov 2024)
- Q. Calculate NA and acceptance angle for fiber with $n_1 = 1.48$, $n_2 = 1.45$. (April 2025)

2.6 Classification of Optical Fibers

- Q. Differentiate between step index and graded index fibers (any 3 points). (Nov 2024)
- Q. Differentiate between step index and graded index fibers (any 3 points). (April 2025)

2.7 Attenuation in Optical Fibers

- Q. What is attenuation in optical fibers? Discuss internal & external factors responsible for attenuation. (Nov 2024)
- Q. What is attenuation? Discuss internal & external factors. (April 2025)

◀ Spontaneous and stimulated emission ▶

♦ Basic principles of Laser ♦

Q. What is laser? Distinguish between spontaneous emission and stimulated emission.

(May-23, Marks 5)

Ans:

- A Laser stands for (Light Amplification by Stimulated Emission of Radiation). It is a device that produces a strong, focused, and highly organized beam of light.

• Properties of Laser Light :

1. Highly Directional

- It travels in a straight, narrow beam without spreading much.

Example : A laser pointer's dot stays small even at a distance, unlike a flashlight that spreads out

2. Monochromatic

- It consists of a single color (wavelength).

Example : A red laser only gives red light, not a mix of colors like a rainbow.

3. Coherent

- All light waves move in the same phase, making the beam very powerful.

Example : Normal light (from the sun or a bulb) has waves that are jumbled, but laser waves are perfectly aligned.

- Lasers are used in medicine, industries, communication, and many other fields due to their precision and intensity.

• Spontaneous Emission vs. Stimulated Emission

- Atoms have electrons that exist in different energy levels. When an electron moves from a higher energy level to a lower energy level, it emits light in the form of a photon.

- This process can happen in two ways:

1. Spontaneous Emission

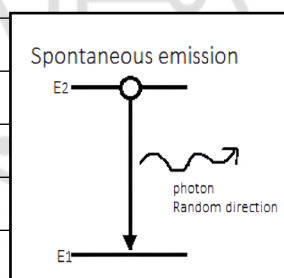
- In this process, an atom releases light on its own without any external influence.
- The emitted photon (light particle) has a random direction and phase. This is how normal light sources like bulbs and the sun work.

Characteristics :

Uncontrolled : Happens randomly, like popcorn popping.

Light is scattered : Photons go in all directions.

Different phases : Light waves are not synchronized.



Example: When a heated metal glows, it emits light spontaneously.

2. Stimulated Emission

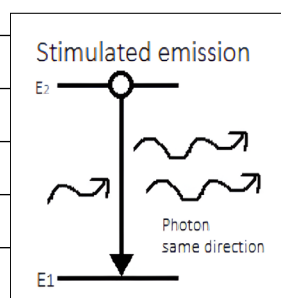
- In this process, an atom releases light because of an external photon hitting it.
- The emitted photon has the same energy, direction, and phase as the incoming photon.
- This is the principle behind lasers.

Characteristics :

Controlled : Happens only when triggered.

Light is identical : Same direction, wavelength, and phase.

Coherent & Amplified : Produces a strong, synchronized beam.



Example: In a laser, light amplification happens due to stimulated emission, which creates an intense and focused beam.

Distinguish between spontaneous emission and stimulated emission

Feature	Spontaneous Emission	Stimulated Emission
Definition	Electron drops randomly, releasing a photon.	Electron drops when triggered, releasing an identical photon.
Cause	Natural decay (no external trigger).	Requires an incoming photon to stimulate emission.
Photon Direction	Random directions (scattered light).	Same direction as the triggering photon (focused beam).
Phase of Light	Incoherent (waves are out of sync).	Coherent (waves are perfectly in sync).
Energy Release	Uncontrolled and random.	Controlled and identical to the input photon.
Example	Light from bulbs, LEDs, or fluorescent tubes.	Light produced in lasers.
Use Cases	Everyday lighting (e.g., lamps, TV screens).	Precision applications (e.g., laser surgery, barcode scanners).

♦ Important Terms in Laser Technology ♦

Q) Define the following terms: (Nov 2024)

- i) Metastable state
- ii) Population inversion
- iii) Stimulated emission

Q. What is stimulated emission? Explain its significance in the production of lasers. (April 2025)

Ans:

1. Metastable State

- A metastable state is an energy level where electrons stay for a longer time than usual before dropping to a lower energy level.
- Normally, electrons in an excited state return to a lower energy level almost instantly (in nanoseconds).
- However, in a metastable state, electrons remain for a longer period (microseconds or milliseconds).
- This delayed transition is important for laser operation because it allows a buildup of excited electrons, making stimulated emission possible.

• How Does a Metastable State Work ?

Excitation:

- Electrons absorb energy and jump to a higher energy level.

Temporary Stay:

- Instead of falling back immediately, some electrons move to a metastable state, where they remain for a longer time.

Laser Action:

- This delay helps achieve population inversion, which is necessary for laser emission.

Example:

- In a helium-neon (He-Ne) laser, helium atoms transfer energy to neon atoms, exciting them into a metastable state. This helps produce the laser beam.

2. Population Inversion

- Population inversion is a condition where more electrons are in a higher energy state than in a lower energy state.
- Normally, electrons prefer to stay in the lowest energy level.
- However, in lasers, an external energy source (such as an electric current or flash of light) is used to push electrons into higher energy levels, creating population inversion.

How Does Population Inversion Work ?

Absorption of Energy :

- Electrons absorb external energy and move to an excited state.

Metastable State :

- Some electrons stay in the metastable state instead of dropping immediately.

More Electrons in Higher Energy Levels :

- Since electrons remain in the metastable state longer, more electrons accumulate there than in the lower level.

Stimulated Emission :

- When a photon of the right energy passes through, it triggers many electrons to fall back at the same time, emitting identical photons, forming a laser beam.

Why is Population Inversion Important ?

- Without population inversion, stimulated emission (which produces the laser beam) would not be possible.
- It ensures that more electrons are ready to release light in a controlled and synchronized manner.

Example :

- In a ruby laser, a flash lamp excites chromium atoms into a metastable state, creating population inversion, which leads to the emission of laser light.

♦ Pumping in Laser ♦

- Pumping is the process of supplying external energy to a laser medium to excite its atoms or molecules to higher energy levels.
- This is done to achieve population inversion, which is necessary for laser action.

Why is Pumping Needed ?

- Normally, atoms stay in a low energy state (ground state).
- For a laser to work, more atoms must be in a high energy state than in a low energy state.
- Pumping provides energy to push electrons to higher energy levels.
- This helps in stimulated emission, which produces laser light.

• Types of Pumping Methods

1. Optical Pumping

- Light energy (from flash lamps or other lasers) is used to excite electrons.

Example : Ruby laser uses a xenon flash lamp for optical pumping.

2. Electrical Pumping

- An electric current or discharge excites electrons in a gas or semiconductor material.

Example : Helium-Neon (He-Ne) laser and semiconductor lasers use electrical pumping.

3. Chemical Pumping

- Energy from a chemical reaction excites the laser medium.

Example : Chemical lasers used in military applications.

4. Thermal Pumping

- Heat energy is used to excite atoms to higher energy levels.

Example : Some gas lasers use thermal energy for pumping.

♦ Active medium & active center ♦

1. Active Medium

- The active medium is the material inside a laser that produces light when energy is supplied. It contains atoms or molecules that get excited and then emit laser light through stimulated emission.

Characteristics of Active Medium:

- It can be a solid, liquid, gas, or semiconductor.
- It must allow population inversion (more atoms in a higher energy state).
- It should support stimulated emission to generate laser light.

Examples of Active Medium in Different Lasers

Ruby Laser → Ruby crystal (solid).

Helium-Neon (He-Ne) Laser → Helium and Neon gas mixture.

CO₂ Laser → Carbon dioxide gas.

Semiconductor Laser → Gallium Arsenide (GaAs) material.

2. Active Center

- The active center is the specific atom, ion, or molecule in the active medium that actually emits laser light.
- These active centers absorb external energy, get excited, and release photons (light particles).

Examples of Active Centers in Different Lasers

Ruby Laser → Chromium (Cr³⁺) ions in the ruby crystal.

He-Ne Laser → Neon (Ne) atoms.

CO₂ Laser → CO₂ molecules.

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Optical Fibers

- An optical fiber is a thin, flexible, and transparent fiber made of glass or plastic that is used to transmit light signals over long distances with minimal loss.
- It works on the principle of total internal reflection (TIR) to guide light through its core.

Critical Angle , Acceptance angle & Numerical aperture

Q. Define critical angle, acceptance angle and numerical aperture for optical fibre. Explain different types of mode of fibre optics communication with diagram. (April-20, 5M)

Q. When light travels denser to rarer medium, calculate the critical angle for the medium. Define acceptance angle, acceptance cone and numerical aperture. (April-20, 5M)

1. Critical Angle (θ_c)

- When a light ray passes from a denser medium (higher refractive index, e.g. glass) to a rarer medium (lower refractive index, e.g. air), it bends away from the normal.
- As the angle of incidence increases, the angle of refraction also increases.
- At one particular angle of incidence, the refracted ray just grazes along the surface (angle of refraction = 90°).

Formula:

According to Snell's law: $n_1 \sin i = n_2 \sin r$

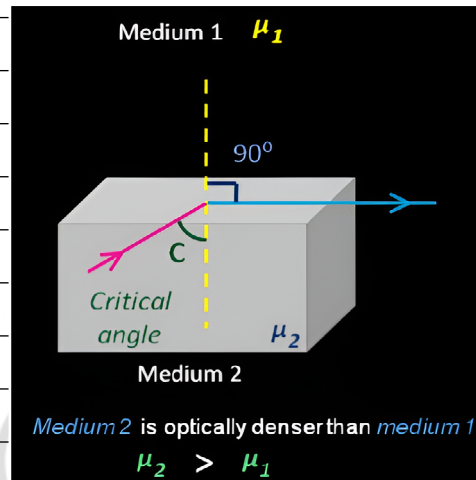
At the critical angle, $i = C$ and $r = 90^\circ$

$$n_1 \sin C = n_2 \sin 90^\circ \Rightarrow \sin C = \frac{n_2}{n_1}$$

where,

n_1 = refractive index of denser medium (core)

n_2 = refractive index of rarer medium (cladding)



Solved Example:

When light travels from a denser medium ($n_1 = 1.5$) to a rarer medium ($n_2 = 1.33$), find the critical angle.

$$\sin C = \frac{n_2}{n_1} = \frac{1.33}{1.5} = 0.887$$

$$C = \sin^{-1}(0.887) = 62.6^\circ$$

$$\text{Critical angle} = 62.6^\circ$$

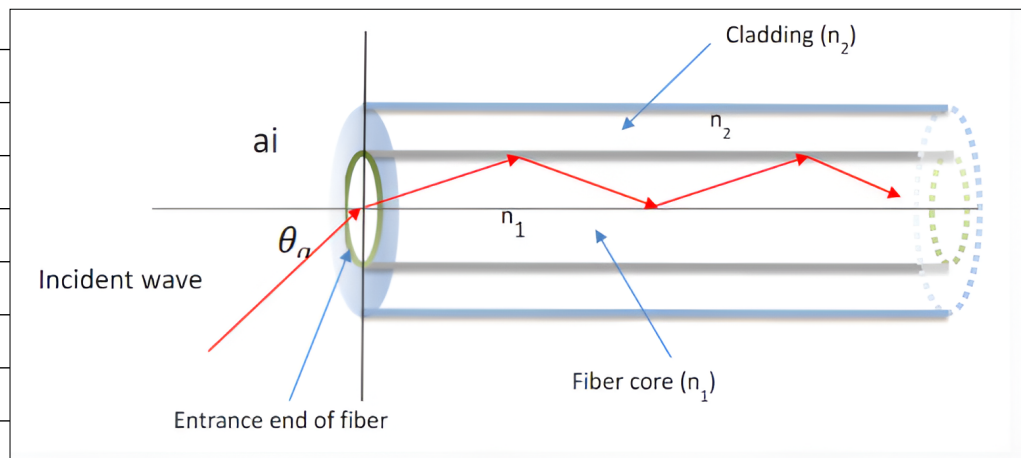
2. Acceptance Angle (θ_a)

The acceptance angle (θ_a) is the largest angle at which a light ray can enter an optical fiber and still get totally internally reflected inside the core.

If light enters at a bigger angle than θ_a , it will not stay inside the fiber it will escape through the cladding.

So,

Acceptance Angle = Maximum entrance angle for which light travels through the fiber by total internal reflection.



Mathematical Derivation

Let:

n_0 = refractive index of air (≈ 1)

n_1 = refractive index of core

n_2 = refractive index of cladding

We know from Snell's law, at the air-core interface:

$$n_0 \sin \theta_a = n_1 \sin r$$

At the core-cladding boundary, for total internal reflection:

$$\sin r = \sqrt{1 - \left(\frac{n_2}{n_1}\right)^2}$$

Substituting this value into the first equation:

$$n_0 \sin \theta_a = n_1 \sqrt{1 - \left(\frac{n_2}{n_1}\right)^2}$$

Simplifying,

$$\sin \theta_a = \frac{n_1}{n_0} \sqrt{1 - \frac{n_2^2}{n_1^2}}$$

Since $n_0 = 1$ for air,

$$\sin \theta_a = \sqrt{n_1^2 - n_2^2}$$

This equation gives the maximum acceptance angle for light to be guided in the fiber.

3. Numerical Aperture (NA)

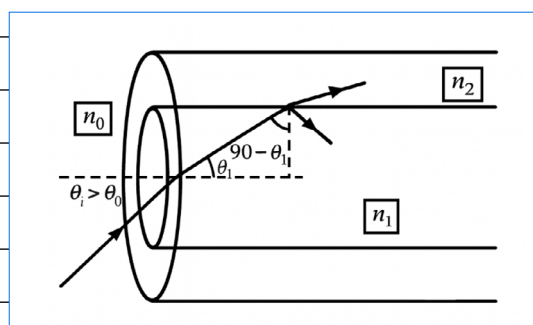
The Numerical Aperture (NA) defines the light-gathering ability of an optical fiber. It determines how much light can be accepted into the fiber for transmission.

Mathematical Expression : $NA = \sin \theta_a = \sqrt{n_1^2 - n_2^2}$

where,

n_1 = Refractive index of the core

n_2 = Refractive index of the cladding

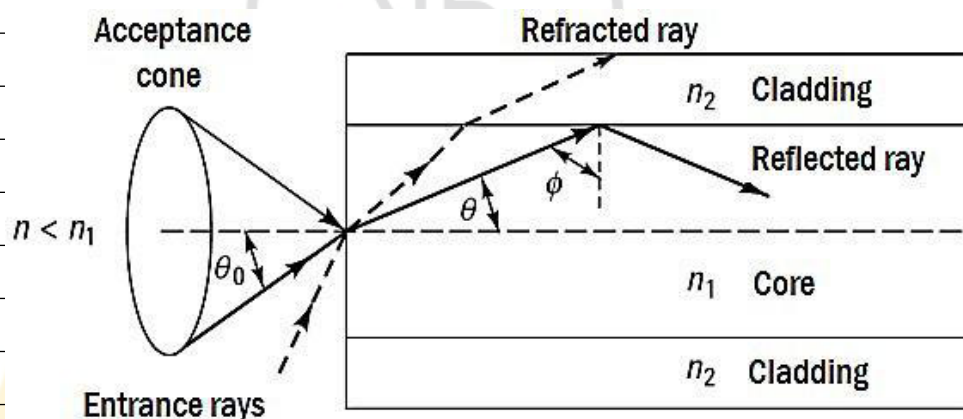


- Critical Angle ensures total internal reflection inside the fiber.
- Acceptance Angle determines how much light enters the fiber efficiently.
- Numerical Aperture (NA) represents light-gathering capacity and depends on core and cladding properties.

3 Acceptance cone

The Acceptance Cone is the cone-shaped region in front of the fiber within which all light rays entering the fiber are guided through the core by total internal reflection.

It is the range of angles at which light can enter the fiber and still travel through it successfully.



Since $n_o = 1$ for air,

$$\sin \theta_a = \sqrt{n_1^2 - n_2^2}$$

where:

n_1 = refractive index of core

n_2 = refractive index of cladding

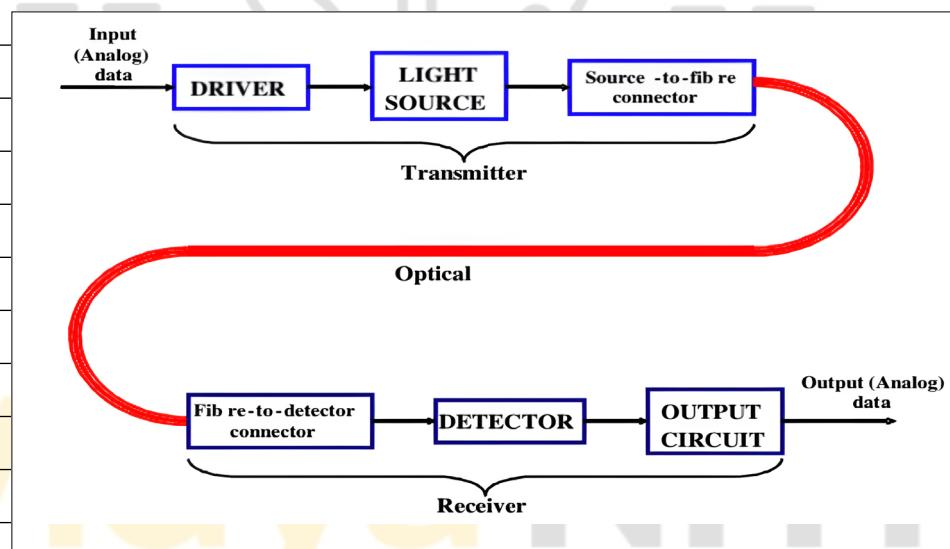
Mismatched fibers or dirt on connectors increase attenuation.

(d) Radiation Loss

Happens when light leaks due to sudden changes in fiber geometry.
More common in multimode fibers.

2.8 optical fiber communication

An optical fiber communication system is a system that transmits information (data, voice, or video) in the form of light signals through optical fibers instead of using electrical signals through copper wires.



The system mainly has three sections:

1. Transmitter Section
2. Optical Fiber (Transmission Medium)
3. Receiver Section

1. Transmitter Section

It converts the electrical input signal (like voice, data, or video) into an optical signal (light pulse).

Components:

a) Driver Circuit

- Takes the input analog or digital data.
- Controls and modulates the light source according to the input signal.
- Ensures the light source turns ON and OFF properly with the data pattern.

b) Light Source

- Converts electrical signal → light signal.
- Uses LED or Laser Diode to generate light.
- The light carries the information in the form of pulses.

c) Source-to-Fiber Connector

- Couples (joins) the light from the source into the optical fiber core.
- Helps efficient light entry into the fiber with minimum loss.

2. Optical Fiber (Optical Link)

- The main transmission path that carries the light signal over long distances.
- Made of core and cladding, working on the principle of Total Internal Reflection (TIR).
- Light reflects inside the core and reaches the receiver with very low signal loss.
- Shown as the red curved fiber path in the diagram.

3. Receiver Section

- It converts the received light signal back into an electrical signal.

Components:

a) Fiber-to-Detector Connector

- Connects the end of optical fiber to the photodetector.
- Ensures proper alignment of the light signal with minimum loss.

b) Detector

- Converts light signal → electrical signal.
- Uses Photodiode or Avalanche Photodiode (APD) as detector.
- Detects the incoming light intensity and generates corresponding current.

c) Output Circuit

- Amplifies and processes the weak electrical signal.
- Restores it to the original form (analog or digital data).
- Gives the final output signal to the destination (speaker, display, or computer).

Working

1. Input data (voice, video, etc.) is given to the Driver circuit.
2. The Driver controls the Light Source (LED/Laser), producing light pulses according to data.
3. The light is passed through the Source-to-Fiber Connector into the Optical Fiber.
4. The Optical Fiber transmits the light signal by Total Internal Reflection.
5. At the receiver end, the light exits the fiber through a Fiber-to-Detector Connector.
6. The Detector changes the light signal back into an electrical signal.
7. The Output Circuit amplifies and processes this signal, giving the original data output.

Advantages of optical fiber communication

(1) High Bandwidth and Data Capacity

- Optical fibers can carry a large amount of data at a very high speed.
- Because light has a very high frequency, fibers can transmit voice, video, and internet data at once.
- More bandwidth means faster communication and more users can be connected.

Example: One fiber can carry thousands of phone calls or HD videos at the same time.

(2) Low Signal Loss

- Signals in optical fibers do not weaken easily.
- They can travel long distances (many kilometers) without much loss of strength.
- This means fewer amplifiers or repeaters are needed, reducing cost.

(3) No Electromagnetic Interference

- Optical fibers use light, not electricity.
- So they are not affected by magnetic or radio waves like copper wires are.
- This gives clear and noise-free communication, even near electrical machines.

(4) Lightweight and Compact

- Optical fiber cables are very thin and light compared to metal cables.
- They are easy to install, handle, and transport.

Example: A long fiber cable weighs much less than a similar copper cable.

(5) High Security

- Light signals stay inside the core of the fiber.

- It is very hard to tap or steal the data without breaking the cable.

- This makes fiber systems safe and secure for confidential communication.

(6) No Electrical Hazard

- Since optical fibers do not carry electric current, there is no risk of shock or short circuit.

- They can be safely used in chemical plants, hospitals, or mines.

(7) Long Distance Transmission

- Because of low loss and high bandwidth, light signals can travel tens or hundreds of kilometers without any problem.

- Fewer amplifiers are needed compared to copper systems.

Numerical problems on parameters of optical fiber

Q. Calculate the numerical aperture and acceptance angle of an optical fibre having $n_1 = 1.49$ and $n_2 = 1.44$

(Jan 23 Oct 22)

ans

Formula : $N.A. = \sqrt{n_1^2 - n_2^2}$

Angle of acceptance $\theta_0 = \sin^{-1} (N.A)$

Given data : $n_1 = 1.49$, $n_2 = 1.44$

$$N.A. = \sqrt{1.49^2 - 1.44^2}$$

$$N.A = 0.38275$$

$$\text{Angle of acceptance } \theta_0 = \sin^{-1} (N.A) = \sin^{-1} 0.38275$$

$$\theta_0 = 22.5^\circ$$

Q. A fibre cable has an acceptance angle of 30° and a core index of refraction of 1.4. Calculate the refractive index of the cladding.

(May 23, Marks 4)

Sol: Given data : $n_1 = 1.4$, $\theta_0 = 30^\circ$

Formula : $\sin \theta_0 = \sqrt{n_1^2 - n_2^2}$

$$\sin 30 = \sqrt{1.4^2 - n_2^2}$$

$$\sin^2 30 = 1.4^2 - n_2^2$$

$$n_2^2 = 1.4^2 - \sin^2 30$$

$$n_2 = 1.3077$$

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